Progress in FDC Project

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The FDC is a general-purpose program package for Feynman Diagram Calculation. We outline previous successes in calculations and focus on its recent progress about automatic deduction the Feynman rules for first principle model, especially for the supersymmetric model, proper evaluation of the rates of multi-final-particle processes and the event generators in the SM and MSSM. A few special applications are presented. The FDC-homepage shows an automatic translation of the FDC results into the HTTP version.

1. Introduction

With the progress in high energy physics, it is obvious that an automate calculation of the physical processes by the perturbative quantum field theory becomes very useful and important. There are many projects for this purpose, such as the Grace[1], CompHEP[2], FeyArt&FeyCal[3], Diana [4] and several others. FDC(Feynman Diagram Calculation) is one of these projects. It was 1992 when we started to write a program for manipulations of one-loop amplitudes [7]. Now a more developed program can be used to automatically deal with any process at tree level, and since then many applications have been made.

The paper is organized as follows. In Section 2 we outline the basic parts of the FDC. Automatic deduction of the Feynman rules for first principle model is presented and especially the procedure for the super-symmetry model is introduced in Section 3. Section 4 is devoted to the rate evaluation of multi-final-particle processes and building the corresponding event generators. In Section 5, a few sub-projects for FDC applications are displayed. Finally a summary is given in Section 6.

2. Basic Parts of FDC

The main parts of the FDC are shown in Fig.1. Its source programs are mainly written in the RE-DUCE and Rlisp, and there is also a Fortran library which supplies necessary basic functions.

The Feynman Diagram plotter is written in C++.

The first two parts *gmodel and diag* [8] were developed in 1993, where *gmodel* is used to deduce Feynman rules for the standard model and *diag* is a Feynman diagram generator which generates Feynman diagrams to any perturbative orders. *psdraw* was constructed to draw the Feynman diagrams from the output of *diag* into a PS file (up to two loops) automatically in 1994. *amp* was finished in 1995 to treat the amplitude square manipulation and related Fortran source generation for tree processes, much improvement had been made and other two optimized methods were introduced later. To properly handle the cancellation among large numbers which is required by the gauge invariance, in the calculations at tree level, a method was proposed [9] and realized in the FDC in 1996. It is a very powerful method to solve the problem in which a t-channel photon peak appears simultaneously with the gauge invariance breaking due to the finite widths of the involved unstable particles. In 1997, *kine* was developed to treat the phase space integration for multi-final-particle processes [10] automatically and improvements were made later. *gm-process* was added to generate multi-final-particle processes in 1998, it was used to generate all the processes on e^+e^-, pp colliders up to four final particles[11]. To automatic deduce the Feynman rules for the minimal super-symmetry model and the R-parity violation model, a modified *gmodel* was developed in 1999∼2000 [12]. *gen_html* was

developed in 2002 to do the translation and presentation of the FDC package results into the *HTTP version*. Therefore most of the results generated by the FDC can be easily put on the FDC-homepage:

`www.ihep.ac.cn/lunwen/wjx/public_html`

Many other options, functions have been implemented in the FDC since 1993.

FDC System

Input For Physical Model

Physical Model Evaluation

Full Feynman Rules

Counterterms

Physical parameters

Input For Physical Peocess
Chose Physical Model and Process

Generation of Feynman Diagram

Amplitude Manipulation

Treatment of Kinematics

Numerical Integration

Latex Version of the model
Http Version of the model
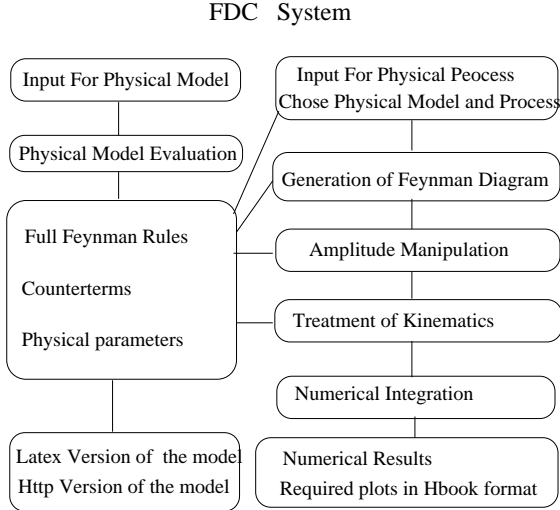
Numerical Results
Required plots in Hbook format

Figure 1. FDC System Flow

3. The Supersymmetric Model

To build up a physical model in the package is the first step. It is done in most packages by inputting all the Feynman rules, counterterms and constants directly. This is not a hard task for the Standard Model, but a very lengthy for more complicate models, such as the super-symmetry model.

For the first principle model, there is a standard way to construct the Lagrangian, to quantize it and give all the Feynman rules and counterterms. In the FDC, we have developed *gmodel* to perform this standard task, i.e, to construct the Lagrangian and deduce the Feynman rules for the SM and the super-symmetry model. Indeed, it is pretty easy to build in any physical model to our

established system, even though developing the program was a very hard job. The standard pro-

To Prepare First Principle Model

Input the description of the first principle model:
    Standard model and it's extensions
    Supersymmetry model and It's extensions

To construct the Lagrangian according to the following conditions:
    Gauge Invariance, Globel Symmetry, Supersymmetry ,
    Yukawa Coupling, $H^+ = H$
 to deduce Feynman rules, Mixing of particles, ...

The Fortran program
 to calculate the mixing
matrix and other deduced
parameters

Latex version of the physical model
Http version of the physical model
    List of all the particles
    List of all the propagators
    List of all the interaction vertices
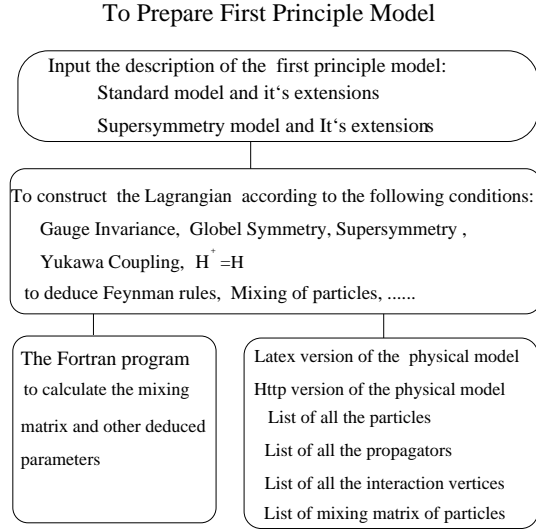   List of mixing matrix of particles

Figure 2. System Flow for *gmodel*

cedure of including a new model in the system is shown in Fig.2. The contents of the input documents are very simple and easy to understand for users, *gmodel* can construct the Lagrangian and then deduce all the mixing matrices, all the Feynman rules from the description of the model in the input file, and then prepare the Latex version of the result and an internal file for later usage in the FDC. A parameterization scheme, i.e, a set of independent input parameters, can be chosen under interface with users. The Fortran source is prepared to calculate the deduced parameters which are needed in following calculations. It has been used to generate the Feynman rules for the MSSM and the R-parity-violated SUSY model.

It is very easy to change many things in the input file of the model, such as the gauge fix terms, notations, the contents of particles, more leptons, more Higgs bosons, soft-breaking terms, forms of the super potential, one can also choose a model which breaks global symmetries such as the lepton number conservation, baryon number conservation, etc.

4. Evaluation of Multi-final particle Processes and Their Event Generators
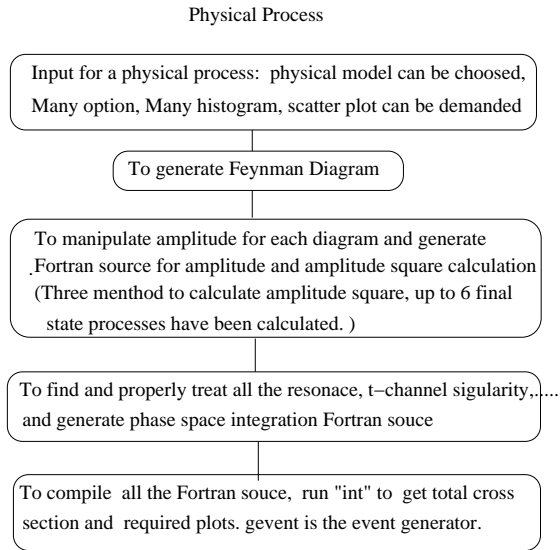
Physical Process

Figure 3. System Flow for gprocess

The integrated script *gprocess* is shown in Fig. 3. It is used to calculate a given tree process, i.e. to prepare all the Fortran sources for the cross section calculation and event generator. The generator supplies an interface in the LesHouches accord format to transfer the generated event to any parton shower MC for the later hadronization processes. The interface Fortran program between the event generator and pythia[5] is implemented. Based on the *gprocess*, *gmprocess* is developed to automatically generate all the processes for a certain topic, such as $e^+e^- \rightarrow 2, 3, 4$ $final$ $particles$, $e^+p \rightarrow 2, 3, 4$ $final$ $particles$ and $pp \rightarrow 2, 3, 4$ $final$ $particles$ in the SM.

As an example, we calculate the all the decay rates of the super-symmetry partners in this way, and compare the results with Isajet[6] at different Snowmass benchmark points[16] of the parameter space. The event generators are generated for all the processes with $2, 3, 4$ final-state particles at different collider energies, such as the LHC, Tevatron and LC, in the SM and MSSM. A HTTP version is written in the FDC-homepage.

5. A Few Sub-Projects in The Application of FDC

Recently we have extended the application of the FDC to a few very special aspects. In these cases, many new programs as well as the modifications of the old ones are developed. The following three subsections are devoted to them.

5.1. FDC-PWA

Based on the FDC package, the sub-project FDC-PWA was completed in 1999. It was developed to generate a complete set of the Fortran sources to do the partial wave analysis on experimental data of decay processes at low energy regions (J/ψ mass, etc.).

We have developed a new *gmodel* to construct effective Lagrangians and deduce the corresponding Feynman rules based on the basic requirements such as Isospin invariance, C-parity invariance, P-parity invariance, G-parity invariance, Lorentz invariance, strange number conservation, charm number conservation, etc. The input is a list of mesons and baryons with values of their Spins (0, 1/2, 1, 3/2, 2, 5/2, 3 , 7/2, 4, 9/2), Isospin, P-parity, C-parity, G-parity, charm number, strange number, masses and widths. The expression of the effective interaction vertices and the propagators for the high spin states are quite lengthy, and the related amplitudes and amplitude squares are complicated. There are many free parameters in the effective model and these parameters will be fixed when the generated program is used to do Likelihood fitting of experimental data.

To work with high spin states and generate the interface to Likelihood fitting program, there are some changes in the Feynman diagram generator *diag*, the amplitude manipulation program *amp* and the kinematics treatment program *kine*. The FDC-PWA has been used in the partial wave analysis for the BES experiments since 2000. The details about the FDC-PWA will be introduced in a different paper[14]

5.2. FDC-EMT

A new part in FDC, FDC-EMT was developed to treat the effective meson model [13] during 2001 to 2002. Part of the results can be found in the FDC-homepage.

5.3. FDC-NRQCD

We have implemented the non-relativistic QCD (NRQCD) formalism for calculating the decay and production rates of the S-wave, P-wave, Color octet, Color Singlet heavy quark meson states such as J/ψ, ψ', B_c in the FDC. The results about J/ψ and B_c production at various colliders can be found in the 2003, 2004 result part of the FDC-homepage. This part of the FDC will be discussed in another paper[15]

6. Summary

The FDC package realizes a completely automatic deduction from physical models to final numerical results for tree processes. We have developed *gmodel* to deduce Feynman rules for a fwe physical models, Standard Model and their extension, Super-symmetry model, and a few Phenomenological models as well, i.e, NRQCD-related heavy quark meson model and Effective Lagrangian model for Partial wave analysis. Three methods are implemented to manipulate amplitudes and generate the the total squared amplitudes. It can be chosen by using different options. We have built in an automatic treatment program of phase space integration for multi-final-particle processes. Many improvements have been made since 1997. *gm-process* has been developed for generating multi-final-particle processes and serves as the event generator for such processes. It was used to generate the event generators for the LHC, Tevatron and LC. The *gen_html* was developed to automatically generate HTTP pages for physical models and multi-final-particle processes. Most of the results are presented in the FDC-homepage.

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